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# Wind Energy System Integration into A Medium-Voltage Grid

Antonio Jaomiary, Sameline Vohirana Fanjanirina Razafison, Solofo Hery Rakotoniaina, Harlin Andriatsihoarana, Edouard Ravalison Andrianarison

Associate Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.

Associate Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.

Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.

Full Professor, CERESA Laboratory, Doctoral School in Engineering and Innovation Sciences and Techniques, University of Antananarivo, Madagascar.

**ABSTRACT:** This article proposes a method for connecting a wind turbine installation to a medium-voltage or high-voltage A electrical network with an operating voltage of 20 kV. This radial network will be used for the controlled injection of intermittent wind-generated electrical energy. To do this, we chose a site with high wind energy potential, the town of Antsiranana, and the test wind turbine is the Enercon E82 E2. To this end, we collected data useful to our study. We then modelled the hybrid system in question. Finally, we used a digital simulation tool to validate the models. We found that the network studied can make a connection with a penetration rate of 10 to 20%.

**KEYWORDS:** Penetration rate, Medium voltage, Wind energy, Wind potential, Controlled injection.

## I. INTRODUCTION

Our work consists of connecting an ENERCON horizontal axis wind turbine to a test network supplying electricity to more than 35,000 households [1]. This network is located in the town of Antsiranana in the north of Madagascar. This site has great wind energy potential. Indeed, the windiest period of the year lasts 6.5 months, with average wind speeds in excess of 24.2 km/h. The windiest month of the year in Antsiranana has an average hourly wind speed of 32.3 km/h. The calmest time of the year gives an average hourly wind speed of 16.3 kilometres per hour [2].

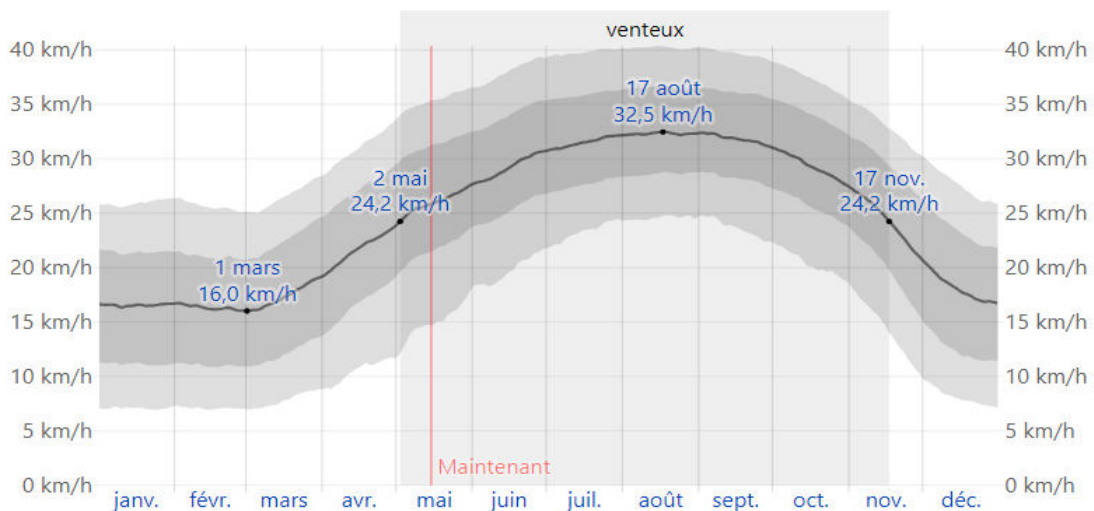


Fig. 1. Average speed in Antsiranana



Further useful data have been consolidated in the table below:

**Table -1** Power network data [3]

| Type of power plant        | Installed capacity [MW] | Available capacity [MW] |
|----------------------------|-------------------------|-------------------------|
| Diesel thermal power plant | 12,72                   | 10,18                   |

As part of this study, we will be operating an onshore wind farm consisting of five 2MW wind turbines, which are mounted in parallel. For these parameters, a wind turbine requires an average wind speed of between 28 and 34m/s, which includes the wind speed in the town of Antsiranana.

**Table -2** Technical specifications of the wind turbine [4]

|                  |                |
|------------------|----------------|
| Model            | Enercon E82 E2 |
| Quantity         | 5              |
| Power            | 2MW            |
| Rotor            | 82 m           |
| Number of blades | 3              |
| Rated speed      | 28 – 34 m/s    |
| Weight           | 7500kg         |

## II. RELATED WORK

Several works deal with the connection of a wind power installation. With the increasing penetration of renewable energies, Gustavo F. Gontijo et al. demonstrate the importance of energy storage systems as they can contribute to preserving the stability of the electrical system. Indeed, wind turbine owners can also benefit from energy storage systems because they can increase their flexibilities [5].

Detlef Schulz estimates that wind power accounts for 42% of all renewable energy sources worldwide. The number of wind turbines around the world is increasing significantly. By the end of 2007, almost 94 GW of wind power had been installed worldwide. Looking at national feed-in tariff improvement models or quota system models, the economic position of this type of energy conversion has improved considerably over the last ten years. According to this study, the number of installations varies from one continent to another: Europe accounts for 75% of installed wind power capacity, America for 15%, Asia for 10%, Africa for 1% and Australia/Pacific for 1.5% [6]. This justifies the importance of our research, since the city of application is an African city with high wind potential.

## III. METHODOLOGY

Since the Enercon E-82 is based on a synchronous machine [4], we will consider a wind turbine using a permanent magnet synchronous generator interfaced with a power electronics unit consisting of a rectifier connected to the stator and an inverter connected to the grid. This structure allows the speed to be varied from 0% to 100% of the machine's nominal rotation speed. The block diagram is shown below:

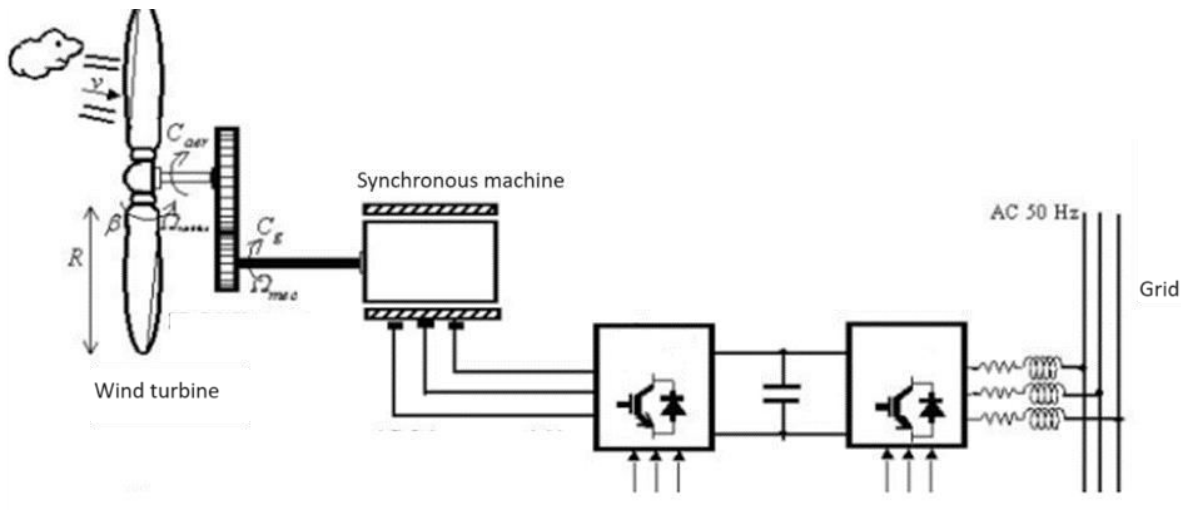


Fig. 2. Grid-connected synchronous turbine wind turbine [7]

The approach adopted is to model the above electro-mechanical chain.

#### A. Modelling the mechanical shaft

The mass of the wind turbine is transferred to the turbine shaft in the form of an inertia  $J_t$  and includes the mass of the blades and the mass of the turbine rotor. The proposed mechanical model considers the total inertia  $J_{total}$  made up of the inertia of the turbine transferred to the generator rotor [9].

$$J_{total} = J_G + G^2 \cdot J_t \quad (1)$$

With:

- $J_G$  : Generator inertia
- $J_t$  : Turbine inertia
- $G$  : Inertia matrix

In other words, the torque of the generator is given by the following relationship:

$$C_g - C_{em} = (J_{total} \cdot S + f) \cdot \Omega_{mec} \quad (2)$$

With:

- $C_g$  : Generating torque
- $C_{em}$  : Electromagnetic torque
- $S$ : Turbine cross-section
- $f$  : friction force intensity
- $\Omega_{mec}$  : Rotor speed  $C$

The speed of the turbine is given by the following relationship:

$$\Omega_{mec} = (C_g - C_{em}) \frac{1}{J_{total} \cdot S + f} \quad (3)$$

#### B. Modelling the permanent magnet synchronous machine

The alternator used in our study is a permanent magnet synchronous generator. This type of machine extracts maximum energy while reducing mechanical stress by eliminating the speed multiplier, which improves system reliability and reduces maintenance costs. This is in contrast to the dual-feed asynchronous machine, which requires a mechanical gearbox [10].

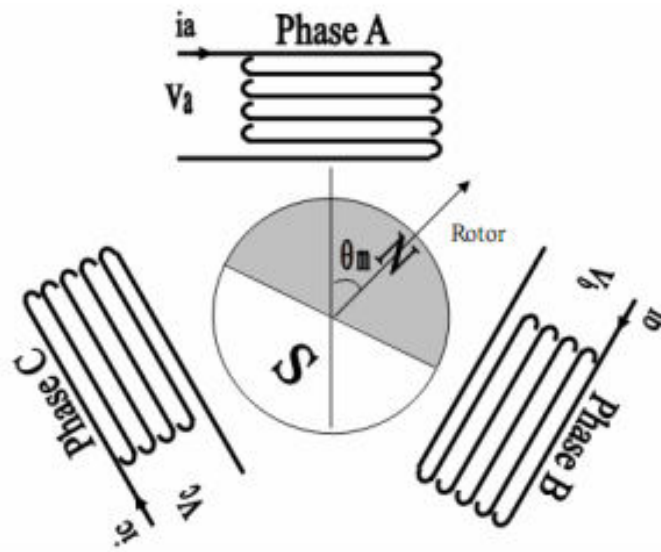


Fig. 3. Exploded view of synchronous machine [10]

The contours of the phase windings, ( $V_a, V_b, V_c$ ) and ( $i_a, i_b, i_c$ ) are the phase voltages and currents. In order to simplify the modelling of the synchronous machine, it is essential to make the following assumptions:

- The magnetic circuit of the machine is not saturated
- The magnetic circuit of the machine is not saturated
- The effect of temperature on the resistors is neglected.
- Hysteresis and eddy currents are neglected.
- The skin effect, which increases resistances and reduces inductances, is neglected.
- The air gap is of uniform thickness.
- The notch effect is neglected.

We have the following mathematical model:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \varphi_a \\ \varphi_b \\ \varphi_c \end{bmatrix} \quad (4)$$

Where:

- $R_s$  : Resistance of the stator phases
- $V_a, V_b$  et  $V_c$  : Stator phase voltages
- $i_a, i_b$  et  $i_c$  : Stator phase currents
- $\varphi_a, \varphi_b$  et  $\varphi_c$  : Total stator fluxes

The magnetic equation of the machine is given by:

$$[\varphi_s] = [L_s][I_s] + [M_{sf}][I_f] \quad (5)$$

The matrix  $[L_s]$  contains constant terms which we group together in  $[L_{s0}]$  and variable terms depending on  $\theta$  which we group together in  $[L_{s2}(\theta)]$ .

$$[L_{ss}] = [L_{s0}] + [L_{s2}] \quad (6)$$

$$[L_{s0}] = \begin{bmatrix} L_{s0} & M_{s0} & M_{s0} \\ M_{s0} & M_{s0} & M_{s0} \\ M_{s0} & M_{s0} & M_{s0} \end{bmatrix} \quad (7)$$

With :

- $M_{s0}$  : Mutual inductance between two phases in the stator
- $L_{s0}$  : Self-inductance of one phase in the stator
- $\theta$  : Angular position of the rotor relative to the stator.
- The coupling between the rotor and the stator is expressed by the following matrix:

$$[M_{sf}] = M_f \begin{bmatrix} \cos(\theta) \\ \cos(2\theta - \frac{2\pi}{3}) \\ \cos(2\theta - \frac{4\pi}{3}) \end{bmatrix} \tag{8}$$

We added Park's transformation to our methodology:

$$[V_{abc}] = [P][V_{dq0}] \tag{9}$$

$$[V_{dq0}] = [P]^{-1}[V_{abc}] \tag{10}$$

$[P]$  et  $[P]^{-1}$  are Park's direct and inverse transition matrices.

Applying Park's transformation to the system of equations, we can express all the vectors in a reference frame linked to the rotor. After the Park transformation, the model becomes :

$$\begin{bmatrix} V_d \\ V_q \\ V_f \end{bmatrix} = \begin{bmatrix} R_s + L_d S & -\omega L_q & 0 \\ \omega L_d & R_s + L_q S & 0 \\ 0 & 0 & R_f + L_f S \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_f \end{bmatrix} + \begin{bmatrix} 0 \\ \omega \cdot \varphi_f \\ 0 \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} R_s + L_d S & -\omega L_q \\ \omega L_d & R_s + L_q S \end{bmatrix} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} 0 \\ \omega \cdot \varphi_f \end{bmatrix} \tag{12}$$

The magnetic equation has the following relationship:

$$\begin{cases} \varphi_d = L_d I_d + \varphi_f \\ \varphi_q = L_q I_q \end{cases} \tag{13}$$

$\varphi_f$  : Magnet flux through the equivalent circuit

#### D. Simulation tool

We used simulink for the simulation part. The block diagram of the installation consists of 10MW wind farms, using five wind turbines of 2MW each, with the five turbines connected in parallel. And the output voltage of the wind turbines is transformed by the 575V/20kV step-up transformer on the 7km line connected to the 20kV grid.

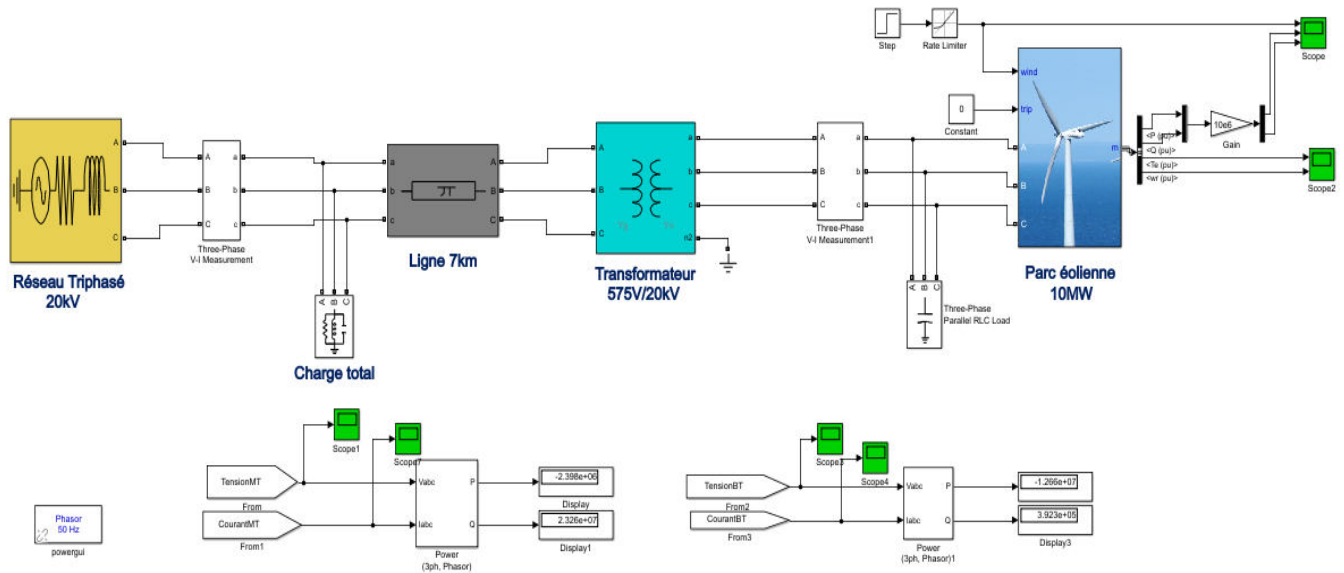


Fig. 4. Block diagram of grid-connected wind turbine

#### IV. EXPERIMENTAL RESULTS

After simulation, here are the characteristic curves obtained:

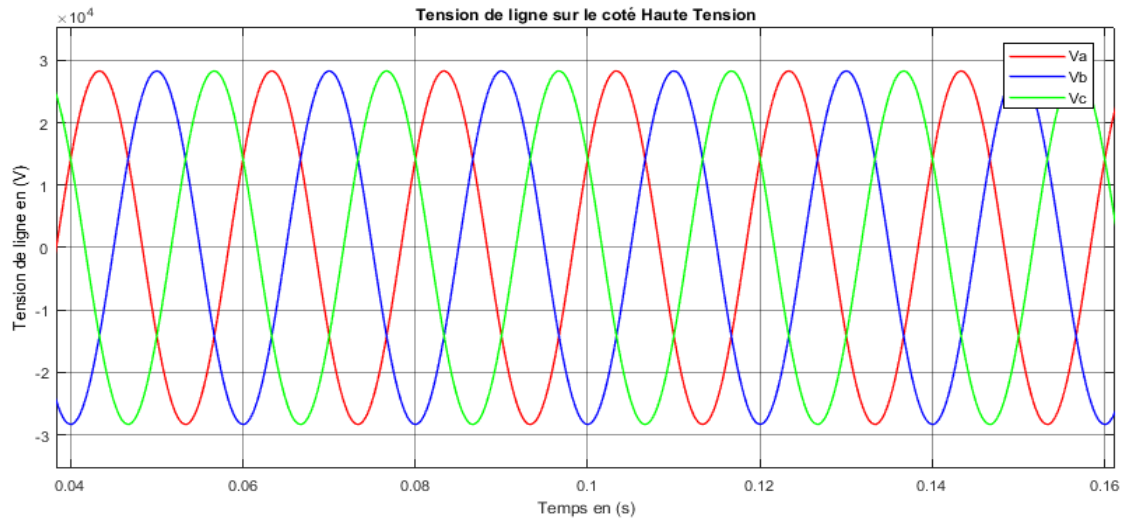


Fig. 5. HT line voltage

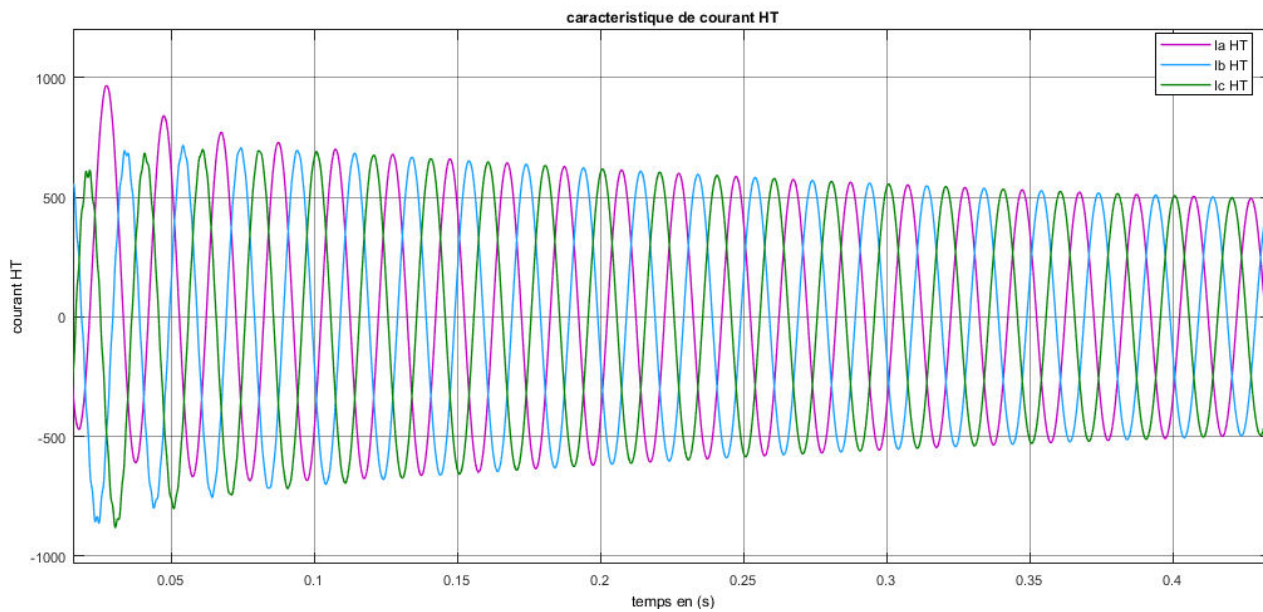


Fig. 6. HT line current

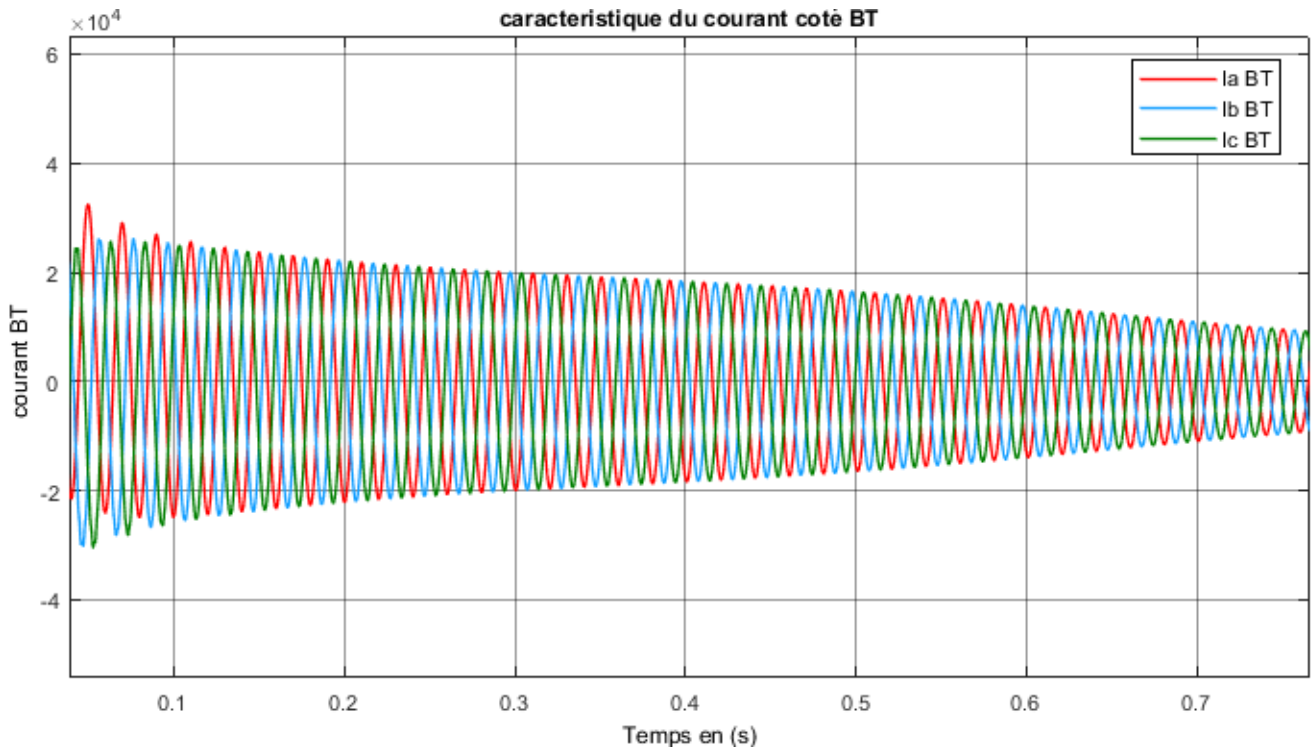


Fig. 7. Turbine output current

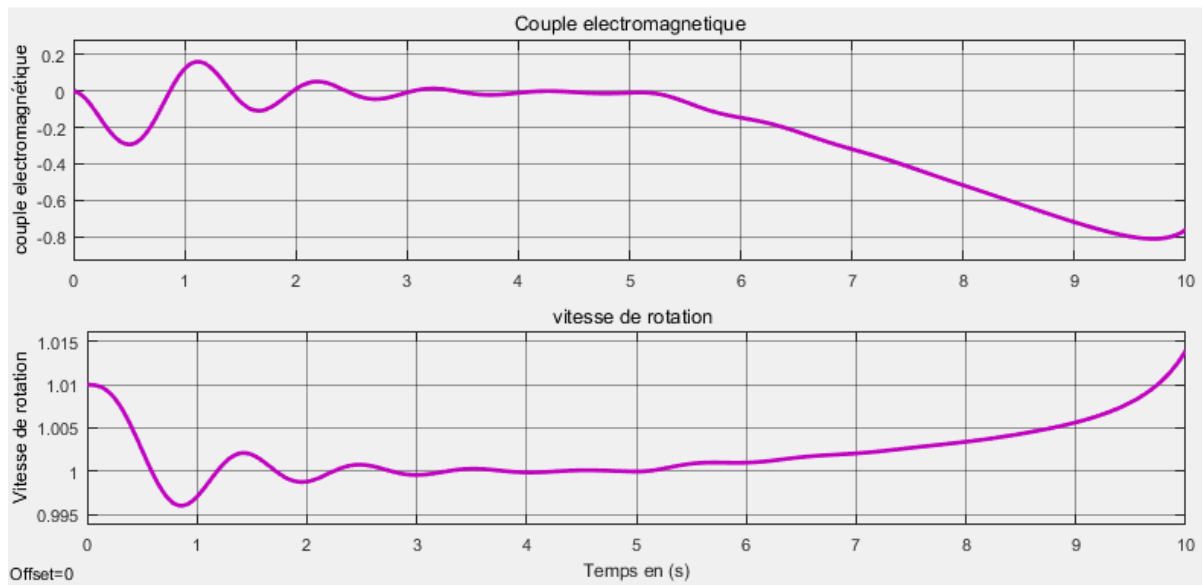


Fig. 8. Electromagnetic torque and machine rotation speed



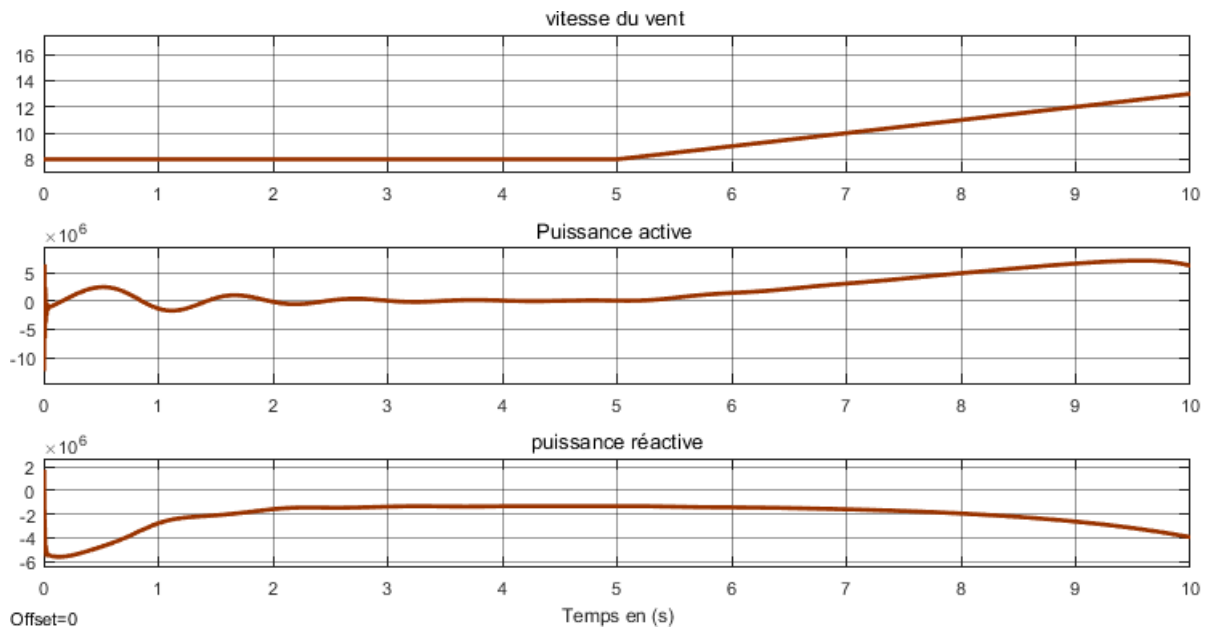


Fig.9. Active, reactive power and wind speed

Figure 5 shows the High Voltage line voltage characteristic. The voltage is sinusoidal with an amplitude of 28kV, i.e. the penetration of the wind turbine increases the line voltage,

The information in Figure 6 shows that during start-up the line current could reach 1000A. However, once the loads have been connected, this value is halved. Once the turbine is up and running, the line current will gradually increase in relation to the wind speed.

Figure 7 shows that the current peaks when the wind turbine is started up, and increases exponentially with time and wind speed.

Figure 8 shows the evolution of the wind turbine's electromagnetic torque. The value of the torque increases as the wind speed increases. However, the speed of rotation of the blade increases proportionally with the wind speed. Finally, Figure 9 shows the evolution of the three characteristic variables of the hybrid system studied: the variation in wind speed as a function of time, the active power of the system and its reactive power. It is important to note that a low average wind speed results in an active power of the order of 0.2 MW, whereas a high wind speed could result in an active power of over 5 MW.

## V. CONCLUSION

Our research has enabled us to understand the principle of hybridising a wind turbine with a medium-voltage electricity grid. The conversion principles identified and analysed provide an understanding of the specific features of these types of installations. Mathematical models were used to describe the system so that numerical simulation could be carried out using simulink. The results obtained confirm that it is possible to achieve a high penetration rate of wind energy in a conventional network (of the order of 40%). This work could contribute fully to the implementation of the strategies and provisions stipulated at the climate conferences, in particular the exploitation of renewable energies.

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